AD-A175 367 THE INTERNATIONAL CONFERENCE ON AMORPHOUS AND LIQUID SEMICONDUCTORS (9TH)(U) PRINCETON UNIV NJ DEPT OF PHYSICS 11 DEC 79 N00014-77-C-0711 1/1

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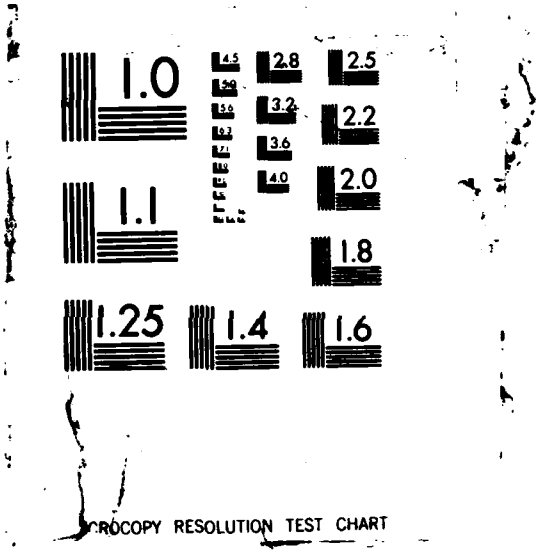
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CROCOPY RESOLUTION TEST CHART

Princeton University
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Contract No. N00014-77-C-0711

The Ninth International Conference on Amorphous and Liquid Semiconductors

Dec. 11, 1979

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I. RESEARCH SUMMARY

A dominant theme in much of the work covered by the grant was the study of disordered systems. Early on, Anderson, Ramakrishnan, Licciardello, Abrahams (Rutgers) and Lee (Bell) produced a new scaling theory of localization. The basic concept involved the use of conductance, in its dependance on microscopic sample size, as the coupling constant of a renormalization group treatment. They showed that the mobility edge corresponds to a fixed point. Experiments on thin films have provided good confirmation of the general ideas and suggest that the inelastic scattering length sets the scale size. In another direction, Ramakrishnan carried out studies of antiferromagnetism and superconductivity, two phenomena which coexist in some rare earth intermetallic compounds. A large, anomalous dip in the critical magnetic field required to destroy superconductivity is observed around the antiferromagnetic phase transition temperature. He could show that slow fluctuations in antiferromagnetic order lead to this effect. Licciardello investigated mechanisms for thermal doping of amorphous semiconductors that have long time transient behavior of their electronic properties. Models were developed to reveal the nature of the metastable, localized states which give rise to this exotic behavior. A new "negative U" device that incorporates the predictions of the theory was proposed. His picture shows an interesting relatioinship for these materials between thermal treatment (history) and electronic processes on the 1 ev scale. The entropic contributions of thermally induced effects, which are amphoteric with respect to doping characteristics, may provide the basis for new electronic devices. The localization problem retains its interest inasmuch as there is still no sastisfactory theory dealing with magnetic field effects. It seems that the field effects on localized wave functions is very different as between weak and strong fields. In another direction for disordered systems, Anerson, Stein, and Kotliar worked on finding an analytic solution of a one-dimensional spin glass model with long range interactions. They uncovered the first example of an analytically tractable model that displays non-mean-field behavior. Anderson, Stein,

and Palmer also developed a new theory of slow relaxation processes in glassy liquids. It has long been known empirically that relaxing variables such as strain, enthalpy, etc. in glassy liquids often obey one or another of the Kohlrausch or Volger-Fulcher laws of time dependence. Both laws are unusual mathematically, mysterious physically, and applicable to a remarkably wide array of materials. They developed a simple model which incorporates strong constrainsts among relaxing variables as its basic premise. Stein, Anderson, and Fu also pursued a non-mean-field approach to the dynamics of spin glasses. Anderson and Kotliar have worked more generally on the interaction-localization problem.

II. Personnel, Publications, Selected Thesis Abstracts

Faculty members supported by the grant included Professors D. Licciardello and D. Stein. In addition, there were numerous research associates, visiting fellows, and graduate students who received support for various intervals. Included are J. Abeles, Apel, A. Chang, M. Evans, Economou, R. Fisch, Kosterlitz, G. Kotliar, A. Kriman, Moreland, K. Muttalib, T. Ramakrishnan, M. Redi, D. Sen, B. Shapiro, L. Sneddon, Tosatti, and H. Yamagishi. Although he received no financial support on the grant, Professor P. W. Anderson provided scientific advice and collaboration throughout.

Publications in roughly chronological order are listed on the immediately following pages.

The subsequent pages contain a selected set of Ph.D. thesis abstracts.

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E. Abrahams, P.W. Anderson, D.C. Licciardello and T.V. Ramakrishnan, "Scaling Theory of Localization: Absence of Quantum Diffusion in Two Dimensions", Phys. Rev. Lett. 42, 673 (1979).

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E. Abrahams and B. Shapiro, "Scaling for the Frequency Dependent Conductivity in Disordered Electronic Systems", Phys. Rev. B24, 4889 (1981)

M. Redi and P. W. Anderson, "Magnetic Order and Energetics of Dipolar Coupling in Magnetic Superconductors", Proc. Math. Acad. Sci. 78, 27-30 (1981)

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-) Albert Chang

Abstract

Within Hopfield's tunneling theory of biological electron transfer, the tunneling rate and the photo-assisted charge transfer extinction (absorption) coefficient are related. As a test of the theory, we perform a high sensitivity, broad band search for the photo-assisted charge transfer band and measure the room temperature transfer rates in the model system of cytochrome c and iron hexacyanide, using a pulsed excitation, time-resolved absorption technique. We obtain an upper limit for the extinction coefficient of $.0024M^{-1}cm^{-2}$ in the wavelength region between 800-1400nm and $.01M^{-1}cm^{-1}$ between 1400-1800nm. The discovery of a charge transfer mechanism of quantum efficieny 10^{-4} from a direct cytochrome c heme visible excitation enables us to measure the charge transfer kinetics and deduce a unimolecular cytochrome c reduction rate of 200+-50s^{-1} and an oxidation rate in the range of $10^4 s^{-1}$. We demonstrate that the measured rates and extinction coefficient are consistent with each other within the tunneling theory. This clarifies some confusion in the literature that they may not be consistent. We also show that the excited state transfer quantum efficiency may be roughly understand in terms of the tunneling theory. In addition, we obtain information on the transfer distance dependence of the tunneling rate by measuring the kinetics in the cytochrome c-$Ru(NH_3)_5$ covalent complex. Here, the transfer distance is around 15-17A, compared to 10-12A in the iron hexacyanide system. From all our results, we estimate a crude value of .9A for the electron wavefunction localization length.

Strongly Disordered Superconductors

Khandker Abdul Muttalib

Abstract

We examine some universal effects of strong non-magnetic disorder on the electron-phonon and electron-electron interactions in a superconductor. In particular we explicitly take into account the effect of slow diffusion of electrons in a disordered medium by working in an exact impurity eigenstate representation. We find that the "normal" diffusion of electrons characterized by a constant diffusion coefficient does not lead to any significant correction to the electron-phonon or the effective electron-electron interactions in a superconductor. We then consider sufficiently strong disorder where Anderson localization of electrons becomes important and determine the effect of localization on the electron-electron interactions. We find that due to localization, the diffusion of electrons becomes "anomalous" in the sense that the diffusion coefficient becomes scale dependent. This results in an increase in the effective electron-electron interaction with increasing disorder. We propose that this provides a natural explanation for the unusual sensitivity of the transition temperature T_c of the high T_c superconductors ($T_c > 10°K$) to damage effects.

B. Kotliar

ABSTRACT

We consider two one dimensional models of disorder.

A percolation model is defined on a one dimensional chain. The bond occupation probability depends on the bond length as

$$P(i,j) = 1 - e^{-\frac{|K|}{|i-j|^{\sigma}}}$$

A percolation threshold exists for $1 \leq \sigma \leq 2$, as a function of K. The critical behaviour is analysed using a renormalization group developped for this problem.

The spin glass model is defined by an Ising chain with hamiltonian

$$H = \sum_{i>j} \frac{J_{ij} S_i S_j}{|i-j|^{\sigma}}$$

The J_{ij} are Gaussian random variables with zero mean and variance J^2 .

We find a phase transition for $\frac{1}{2} < \sigma < 1$. For $1 < \sigma < \frac{2}{3}$ the system has classical critical behaviour. Near $\sigma = 1$ we find a smooth specific heat. We investigate the critical behaviour near the upper and lower critical range using the renormalization group and an ϵ expansion around the lower and upper critical range, $\sigma = \frac{2}{3}$ and $\sigma = 1$.

D. Emin

ABSTRACT

Small Polarons are studied using the Molecular Crystal Model of Holstein. A quadratic component is included in the electron-lattice interaction. When this component is sufficiently large, consecutive small polaron hops are correlated: the hop rate in a given direction depends on the time and direction of the last hop, and conventional methods for determining the mobility fail. Here the hopping mobility is determined using a method due to Emin which exhibits these correlations explicitly. A new expression is derived for the mobility in terms of the correlated hop rates. The apparent short-time divergence of the rate for consecutive antiparallel hops (return hops) is found to be a consequence of the failure of the nonadiabatic approximation. Although the correct return hop rate is then found to be finite, it may still be large, and the mobility is studied for the situation in which return hops dominate the motion. The correlated hop rates are found to depend only on the evolution of the lattice from an initial minimum-energy configuration, as is the case in the absence of quadratic coupling. Using this fact, efficient numerical integration routines are developed to determine the mobility. In contrast to the low, activated mobilities predicted by uncorrelated hopping theories, moderate ($\sim$ 1 cm^2/V-sec), almost temperature-independent mobilities are observed for large quadratic coupling. This is proposed to explain the mobility in molecular crystals such as anthracene.

D. Seo

ABSTRACT

Though the Lagrangian of quantum chromodynamics is well known, it has proven extremely difficult to derive precisely all its consequences to compare with experiment. Approximations based on physical reasoning must be made. One method is to calculate the effective action for some particularly simple configuration of gluons and use this to analyse an arbitrary system of interacting quarks.

In the first chapter, the one-loop correction to the gluon propagator is computed in two different ways - dimensional regularization and Schwinger's proper time method. The renormalization mass parameters appearing in the two treatments can then be related and the exact one-loop effective action of a constant gluon field can be expressed in terms of the experimentally determinable $\Lambda_{\overline{MS}}$.

In the following chapter, the interaction of a heavy quark-antiquark pair governed by this action is considered and it is shown how the spectrum, and, in particular, the spin splittings of the bound states can be found. Due to asymptotic freedom, a massive quarkonium is analogous to a non-relativistic eletromagnetic system. At short distances, the results are the same as those derived from perturbation theory though, for example, the hyperfine structure arises in a different way. At large distances, the analysis is qualitative but our results agree with the predictions of strong coupling lattice gauge theories.

Albert Chang

Abstract

Within Hopfield's tunneling theory of biological electron transfer, the tunneling rate and the photo-assisted charge transfer extinction (absorption) coefficient are related. As a test of the theory, we perform a high senstivity, broad band search for the photo-assisted charge transfer band and measure the room temperature transfer rates in the model system of cytochrome c and iron hexacyanide, using a pulsed excitation, time-resolved absorption technique. We obtain an upper limit for the extinction coefficient of $.0024M^{-1}cm^{-2}$ in the wavelength region between 800-1400nm and $.01M^{-1}cm^{-1}$ between 1400-1800nm. The discovery of a charge transfer mechanism of quantum efficieny 10^{-4} from a direct cytochrome c heme visible excitation enables us to measure the charge transfer kinetics and deduce a unimolecular cytochrome c reduction rate of 200+-50s^{-1} and an oxidation rate in the range of $10^4 s^{-1}$. We demonstrate that the measured rates and extinction coefficient are consistent with each other within the tunneling theory. This clarifies some confusion in the literature that they may not be consistent. We also show that the excited state transfer quantum efficiency may be roughly understand in terms of the tunneling theory. In addition, we obtain information on the transfer distance dependence of the tunneling rate by measuring the kinetics in the cytochrome c-$Ru(NH_3)_5$ covalent complex. Here, the transfer distance is around 15-17A, compared to 10-12A in the iron hexacyanide system. From all our results, we estimate a crude value of .9A for the electron wavefunction localization length.

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